S13 Discovery of Radio-loud Black Hole Candidates Interacting with Molecular Gas in the Galactic Center

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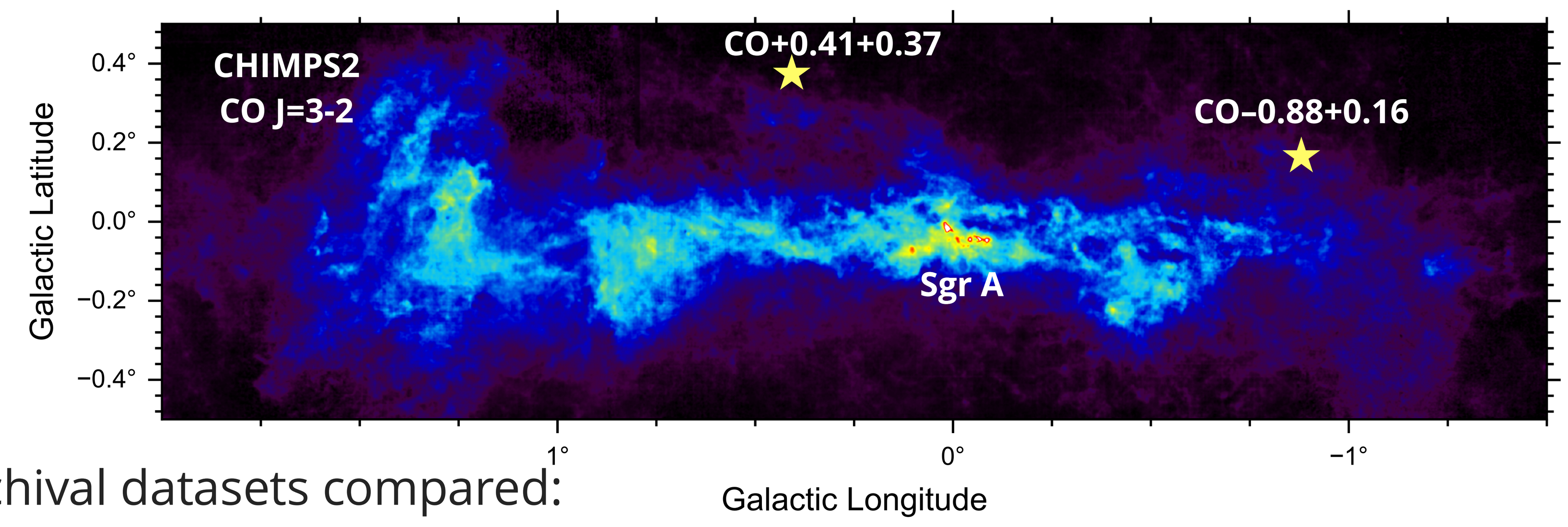
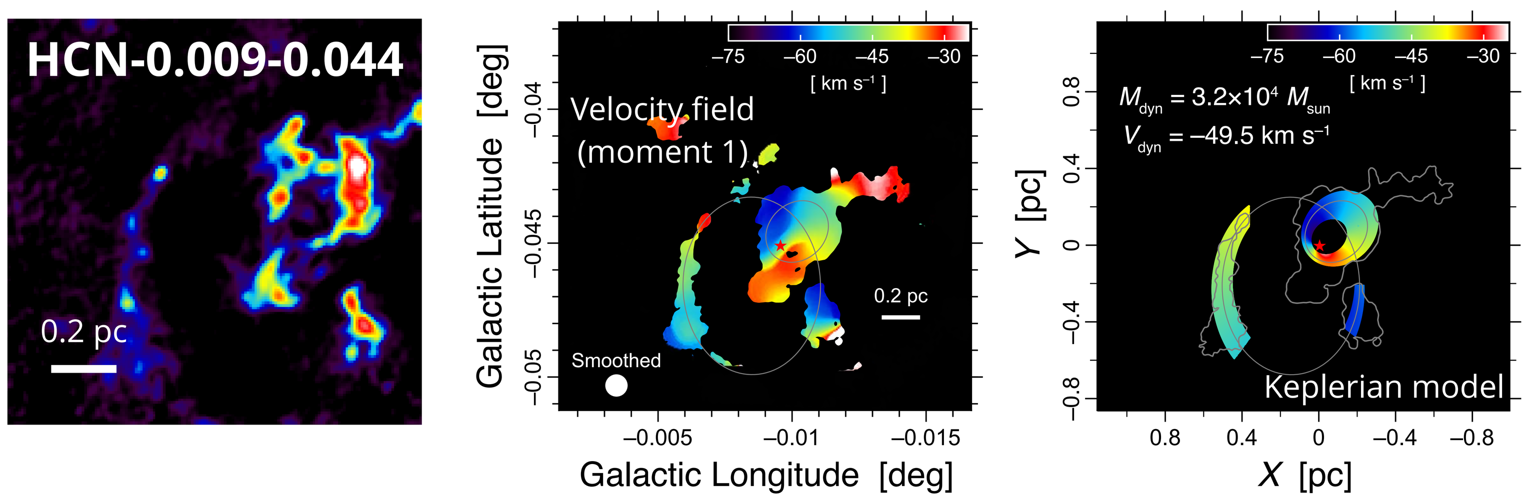
High-velocity(-dispersion) compact clouds (HVCCs)

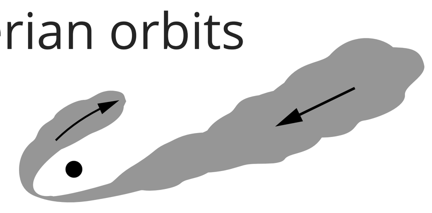
- ~200 HVCCs identified in the Central Molecular Zone (e.g., Oka et al. 2022)
- Compact sizes ($d \lesssim 5$ pc)
- Extremely **broad velocity widths** ($\Delta V \gtrsim 50$ km s^{-1})
- Most have no counterparts at other wavelengths



Hidden intermediate-mass black hole? (Takekawa et al. 2019)



- ALMA reveals two distinct components in HVCC HCN-0.009-0.044: a ring-like structure and a stream-like structure.
- Their kinematics are well explained by two Keplerian orbits around a single point mass of $3 \times 10^4\ M_\odot$

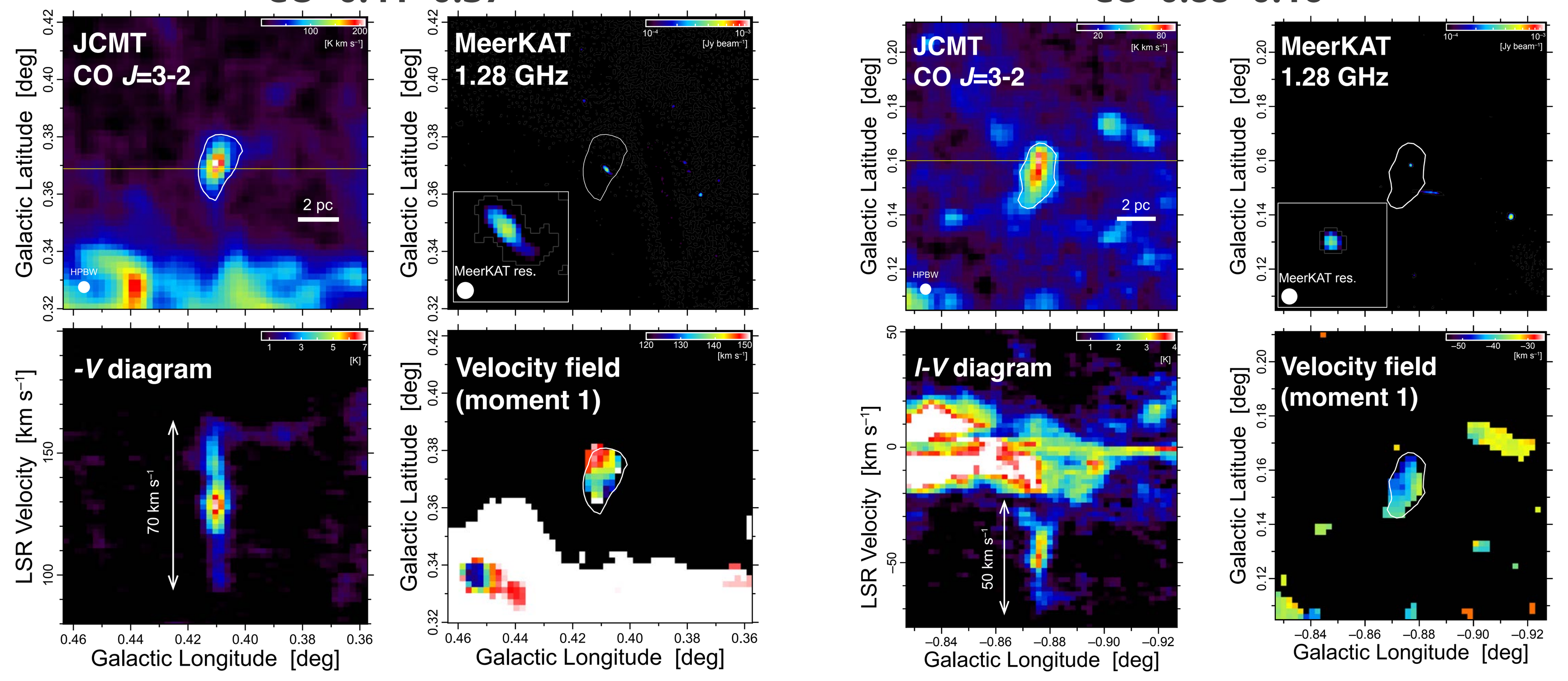


However, no clear counterparts
→ difficult to confirm the (IM)BH interpretation.

Archival datasets compared:

- MeerKAT 1.28 GHz continuum (Heywood et al. 2022)
- JCMT CHIMPS2 CO J=3-2 survey (Eden et al. 2020)

Two HVCCs with compact radio counterparts were identified.



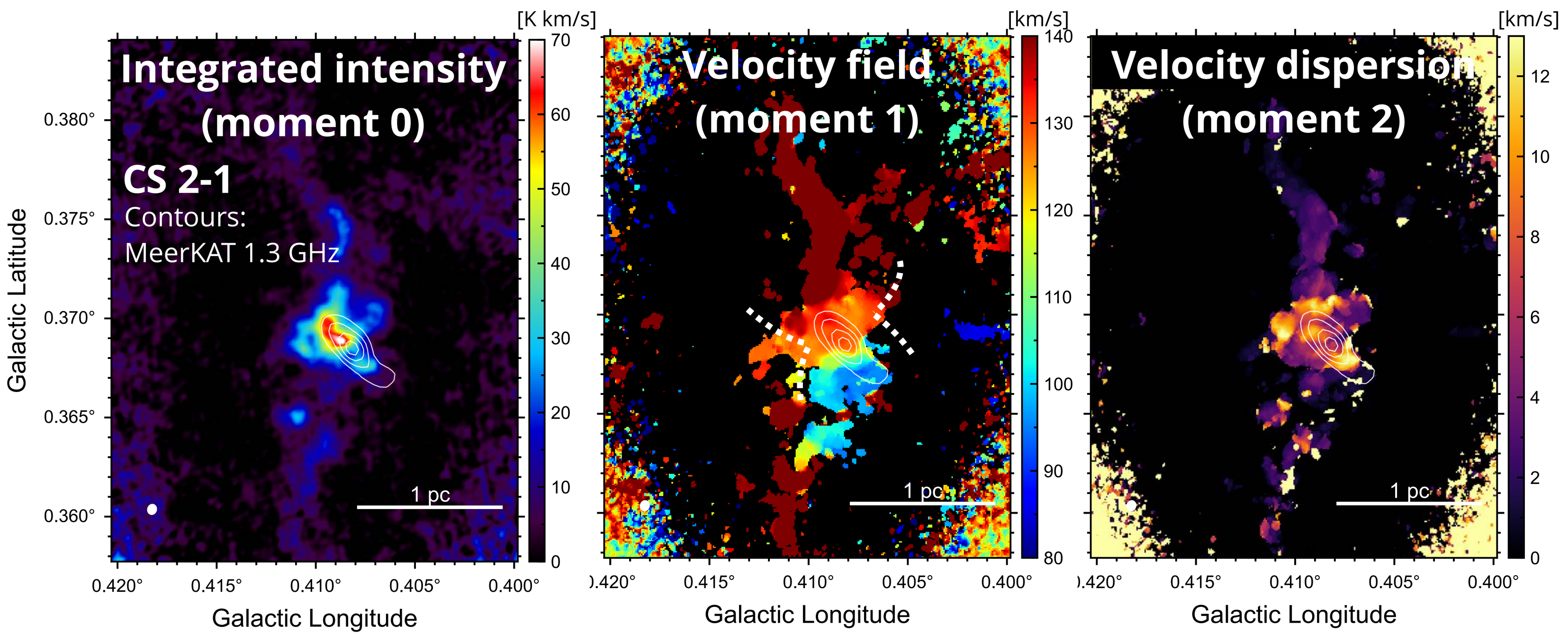
ALMA resolving the two HVCCs

HVCCs have been searched for compact counterparts mainly in the context of gravitational interactions. Our results suggest that some HVCCs may also be useful probes of jet–ISM interactions.

Cycle11 observations

- 12m+7m (+TP for Band 3)
- Target lines and continuum:
  CS J=2–1, J=1-0, SiO J=2-1, J=1-0
  HCN J=1-0, HCO+ J=1-0 etc.
  43, 49, 100 GHz (Band 1, 3)
- $\theta_{\rm HPBW} \sim 2''$ (~0.08 pc@8 kpc)

CO+0.41+0.37



- Molecular gas concentration along the radio source
- Clear velocity gradient
- Enhanced velocity dispersion
- Red/blue velocity pattern associated with cone-like structures, resembling a **bipolar outflow**

Physical properties estimated by CS J=2-1
(assuming LTE with $T_{\rm ex} = 10$ K, $\tau \ll 1$, $[{\rm CS}]/[{\rm H_2}] = 10^{-8}$)

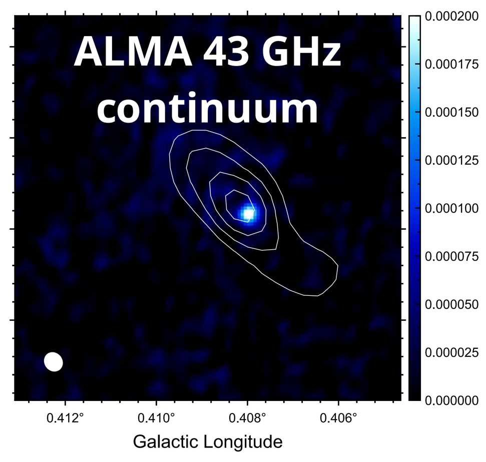
$M_{\rm LTE} = 10^2\ M_\odot$

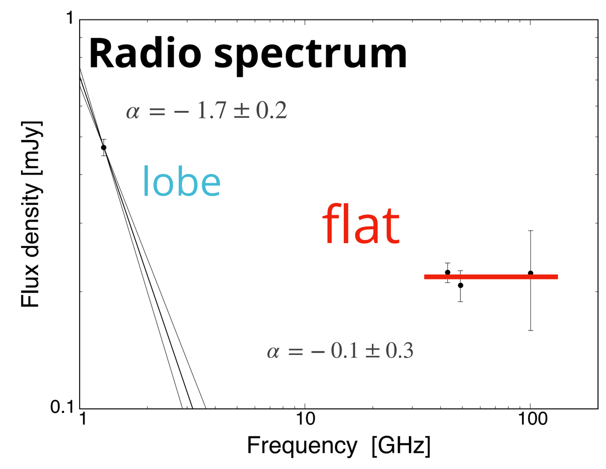
$t_{\rm dyn} = (0.4\ {\rm pc})/(20\ {\rm km/s}) = 2 \times 10^4$ yr

$E_{\rm kin} = \frac{1}{2}(10^2\ M_\odot)(20\ {\rm km/s})^2 = 4 \times 10^{47}$ erg

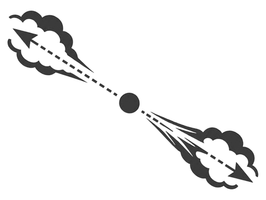
$P_{\rm kin} \sim 2 \times 10^2\ L_\odot$

The estimated mechanical power is comparable to or higher than the Herschel-based dust luminosity limit ($\lesssim 10^2\ L_\odot$).
→ Protostellar origin energetically disfavored
(Too powerful for a protostar)



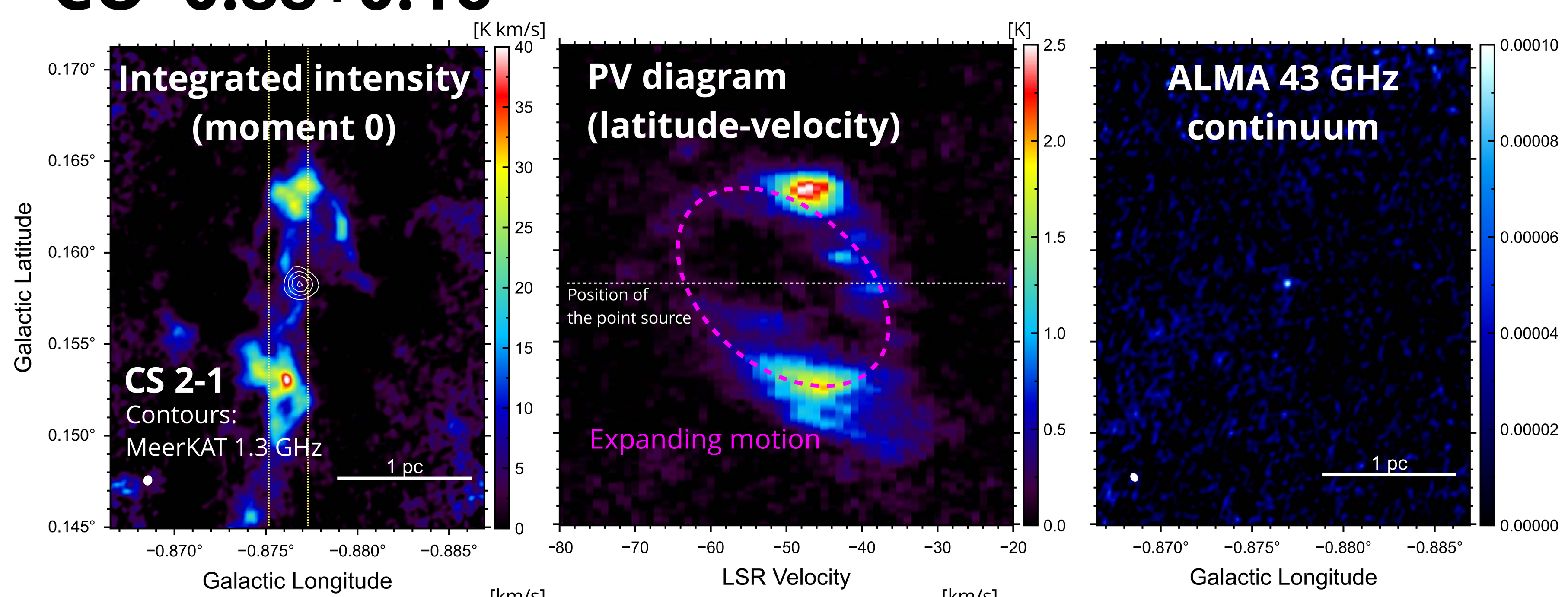


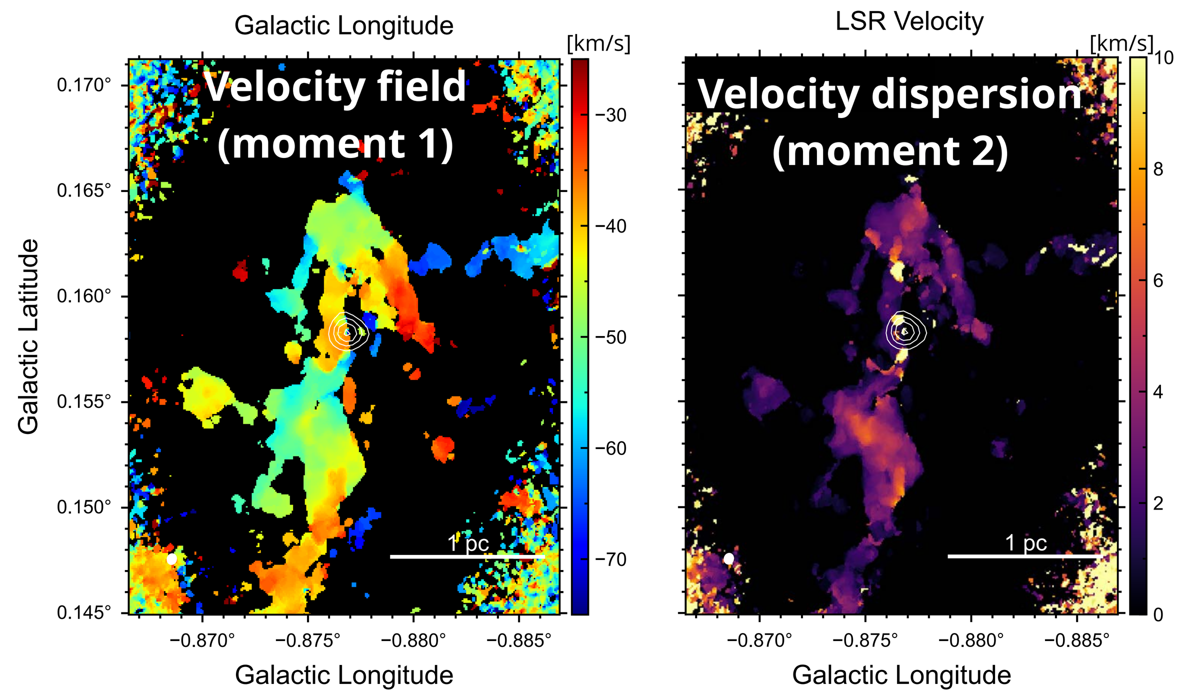
- MeerKAT: elongated steep-spectrum nonthermal emission
- ALMA: compact flat-spectrum point source
- Extended MeerKAT emission is not detected with ALMA
- The nonthermal elongation may trace a **jet**-related lobe
- **The flat-spectrum core is consistent with a Galactic black hole source**
- The radio luminosity ($L_{\rm R} \sim 10^{29}$ erg/s) would imply $L_{\rm X} > 10^{34}$ erg/s for a typical X-ray binary, yet the source is **faint in X-rays** ($L_{\rm X} \lesssim 10^{32}$ erg/s)

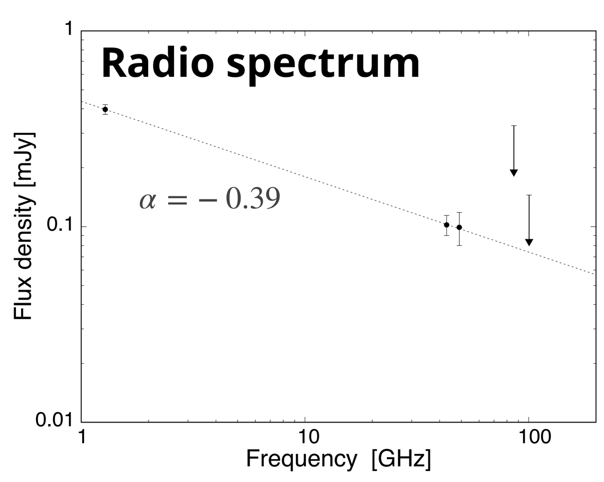


→ Radio-loud black hole candidate driving a molecular outflow and radio jet

CO−0.88+0.16







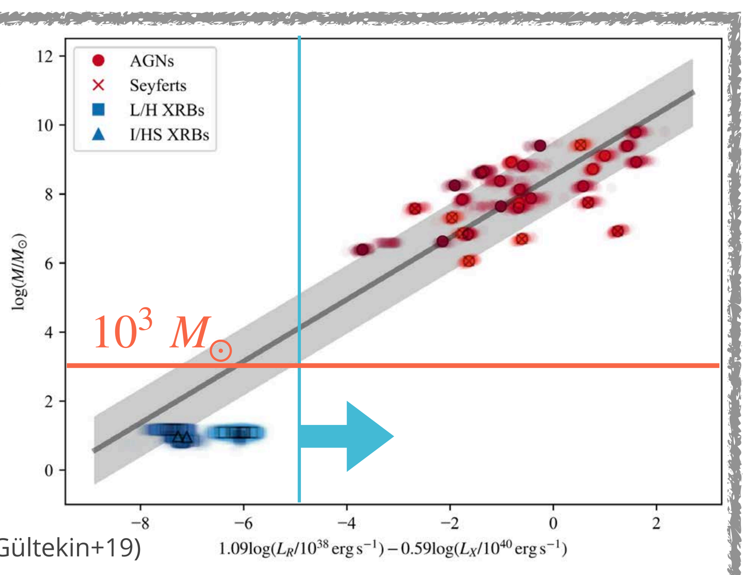
- Symmetric north–south molecular extensions
- **Bipolar jet/lobe-like morphology** with **expanding motion**
- **Nonthermal point source**
- Faint in X-ray ($L_{\rm X} \lesssim 10^{32}$ erg/s, XMM upper limit)

Another radio-loud black hole candidate
Possibly linked to bow-shock compression or a jet cocoon from past jet activity.

The two newly found point sources have:

- Radio luminosity: $L_{\rm R} \sim 10^{29}$ erg/s
- X-ray luminosity: $L_{\rm X} \lesssim 10^{32}$ erg/s

If these sources follow the fundamental plane of BH activity, they may be **IMBHs** ($M_{\rm BH} \gtrsim 10^3\ M_\odot$)



A new population of radio-loud black hole candidates in the Galactic center